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DEVELOPMENT OF HIGH-ENERGY SOLID PROPELLANT FORMULATIONS FINAL SUMMARY REPORT

VOLUME 2: PROPELLANT HANDLING MANUAL

TECHNICAL DOCUMENTARY REPORT NO. RPL-TDR-64-10

JANUARY 1964

ROCKET PROPULSION LABORATORY
SOLID ROCKET DIVISION
AIR FORCE SYSTEMS COMMAND
EDWARDS, CALIFORNIA

PROJECT NO. 3059
TASK NO. 305902
PROGRAM STRUCTURE 750G

PREPARED UNDER CONTRACT AF04(611)-8179

BY

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RPL-TDR-64-10

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Rocket Propulsion Laboratory
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Project No. 3059, Task No. 305902
Program Structure 75[illegible]

(Prepared Under Contract No. AF04(611)-8179)
Rocketdyne, a Division of North American Aviation, Inc.
6633 Canoga Avenue, Canoga Park, California

FOREWORD

This report and handling manual was prepared by the Solid Propulsion Section of the Rocketdyne Research Department and the Industrial Hygiene Unit in partial fulfillment of Contract AF04(611)-8179, Space Systems Division, Edwards Air Force Base, Air Force Systems Command, United States Air Force. A companion technical report issued simultaneously as Volume 1 covers experimental results obtained with beryllium propellants.

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ABSTRACT

This report outlines the purpose, objectives, and results of the industrial hygiene program conducted in support of Contract AF04(611)-8179. A detailed description of the facilities and methods utilized for the control of beryllium during the production and static test firing of beryllium-containing propellants is presented. Environmental sampling data as well as the data collected from a downwind sampling network are included. The data demonstrate the feasibility of producing and static test firing beryllium-containing propellants.

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INTRODUCTION

Two tasks are specified in Contract AF04(611)-8179 for the development of high-energy solid propellant formulations containing beryllium. Task I was delineated as industrial hygiene to cover all phases of the development program. Included in Task I is the preparation of a toxic materials handling manual to provide information on the handling and use of beryllium in various propellants. Task II involves the technical task of propellant development and is discussed in Volume 2 of this report.

For ready reference and orientation purposes, Task I of the experimental program is reproduced in detail below.

Earlier work in the industrial hygiene area is included in the previously issued quarterly reports for this program (Ref. 1 through 3).

TASK I: INDUSTRIAL HYGIENE PROGRAM

1. Determination of the beryllium concentration in the atmosphere in the neighborhood of the plant shall be made for both long term and peak load cycles. Soil samples shall be taken at periodic intervals in the neighborhood of the plant and subjected to analysis to determine the beryllium concentration. Working conditions and plant effluents will be monitored on a routine basis.
2. Program plans in the over-all area of industrial hygiene and testing procedures shall be coordinated with the Surgeon, Deputy Commander Aerospace System, AFSC, USAF, Attention: Captain Owen Kittilstad, Air Force Rocket Propulsion Laboratory (RPF00) (Development) (DCD-1), through the Procuring Contracting Officer prior to initiation of effort.

1.0 BERYLLIUM PROPELLANT FACILITIES

1.1 Introduction

Several years ago, Rocketdyne initiated a study of the use of beryllium in solid propellants. It was decided to build research facilities which would allow for easy expansion to handle development-size motors. Two approaches were selected: (1) to have laboratory-scale (up to 1 pound of propellant) formulation and test capability at the Propulsion Field Laboratory, Santa Susana, utilizing containment chambers whenever possible, and (2) to have unconfined larger-scale mixing and firing in a remote portion of the Nevada Test Facility.

1.2 Propulsion Field Laboratory, Santa Susana

1.2.1 The beryllium facility at the Propulsion Field Laboratory consists of a formulation building and a unique containment system for both mixing and firing. The laboratory (shown in Fig. 1 and 2) is utilized only for handling beryllium-containing propellants and ingredients, and is used for slurrying beryllium metal powder into binder, propellant casting, motor preparation, and preparing physical test specimens. Equipment for conducting special tests such as burning rate, compatibility, and heat of combustion also are located in this laboratory. All work with beryllium powder is done in a dry box and a hood so that the powder is kept within the confined areas. Both the dry box and the hood are attached to a suction blower which pulls the air through two high-efficiency filters. The output of the blower has been monitored, and the results have indicated that the filters are greater than 99% efficient.

1.2.2 The propellant mixing and firing system is located near the beryllium laboratory. Both the mixer (Baker-Perkins vertical; 1-pint capacity) and the firing stand (2-inch-diameter ballistic motor) are completely enclosed during operation. The exhaust from the motor firing vents through two chambers; the first is a surge tank, and the second is a water spray chamber. The gases then vent to atmosphere through a high efficiency filter

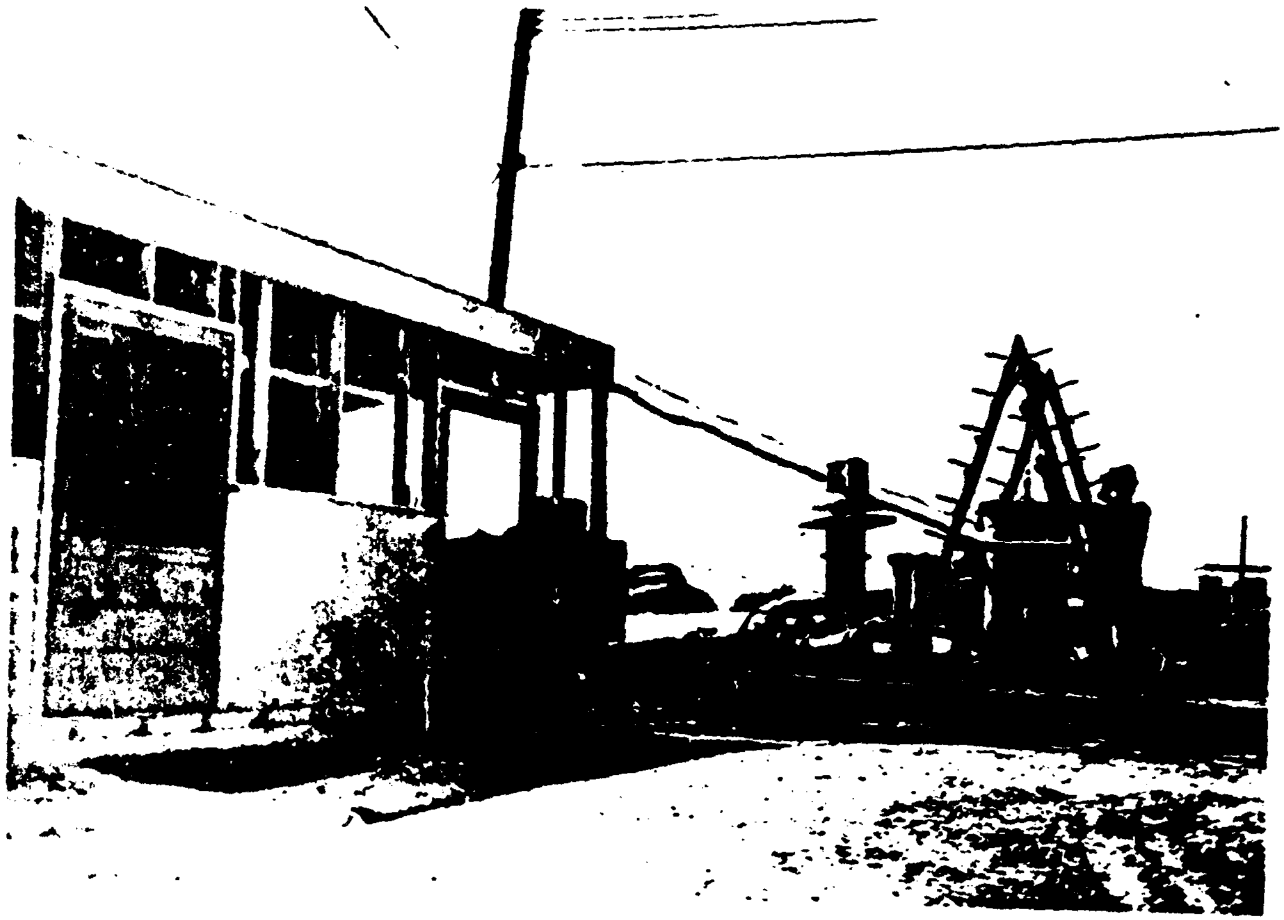

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Figure 1. Toxic Propellant Laboratory

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Figure 2. Interior of Beryllium Laboratory

system. The mixer containment chamber also vents through the same two surge tanks which are so sized that in case of a mixer fire, all the gases would be scrubbed and filtered before release to the atmosphere. All of the water from the spray chamber, as well as all wash water from the area, is returned to a large catch tank where it can be decontaminated prior to disposal. The mix cycle and the motor firing sequence are operated from the nearby sealed blockhouse control room. The facility is shown in Fig. 3, and the details of its construction are shown in Fig. 4.

1.2.3 All operations in the beryllium facility are conducted under strict industrial hygiene control. The operators wear a complete set of protective clothing and have respirators available for instant use should emergencies arise.

Each operator showers before leaving the area and prior to dressing in his street clothes. Continuous air samples are taken during all operations in the area.

1.3 Nevada Test Facility

1.3.1 The existing solid propellant research facility in Nevada was designed to conduct propellant processing and testing on a pilot-plant scale that would be too hazardous or involve quantities of hazardous materials too large to be handled at the Propulsion Field Laboratory. Where it is necessary to handle more than 1-pound grains of beryllium propellants, the program is conducted at the Nevada facility.

1.3.2 The Nevada facility is shown in Fig. 5, and a photograph of the area is shown in Fig. 6. The buildings were designed as the first stage in the development of an advanced high-energy solid propellant facility. The buildings which have been completed are shown in solid lines in Fig. 5. The buildings shown in broken lines are scheduled for construction in the near future.

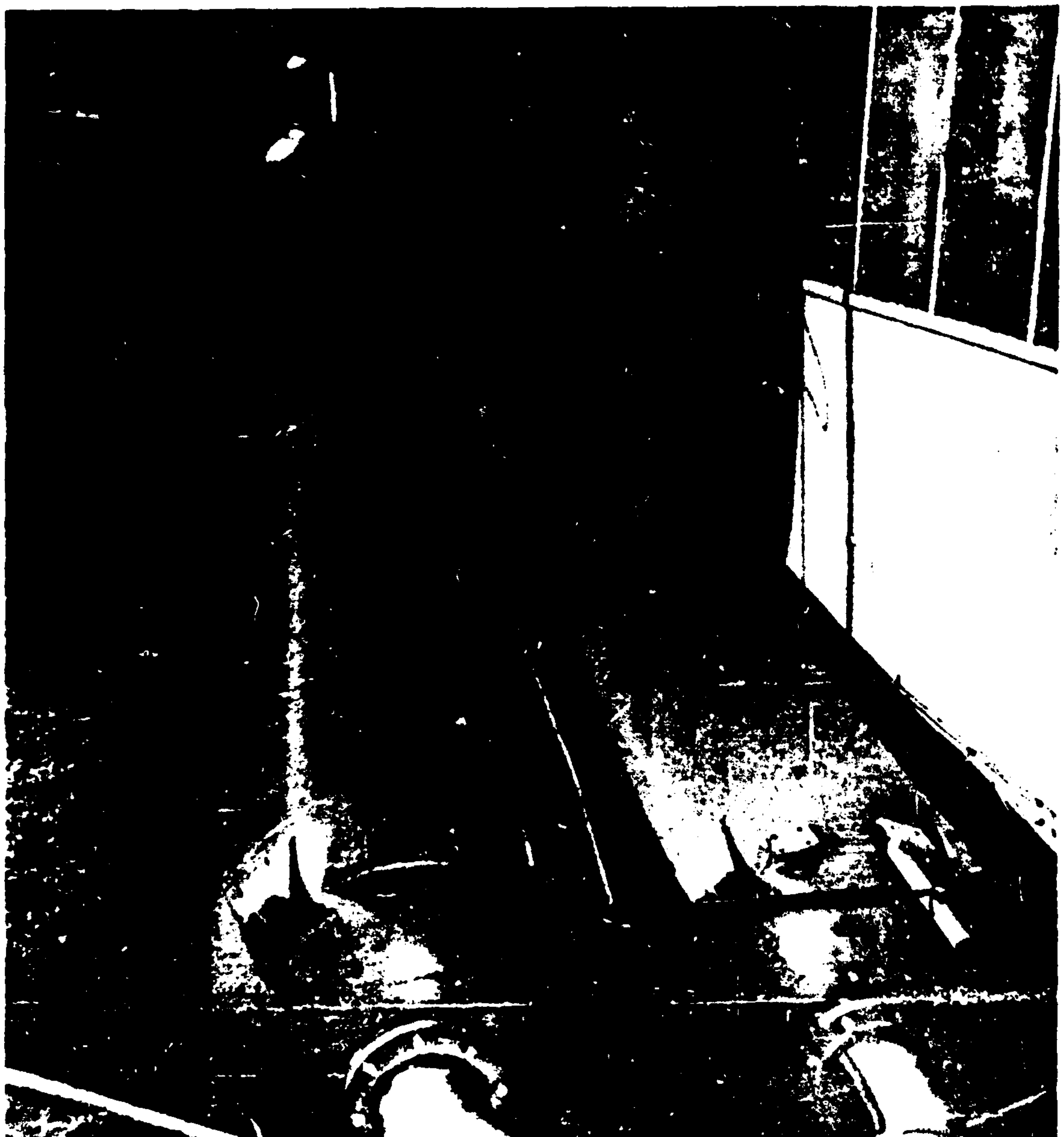

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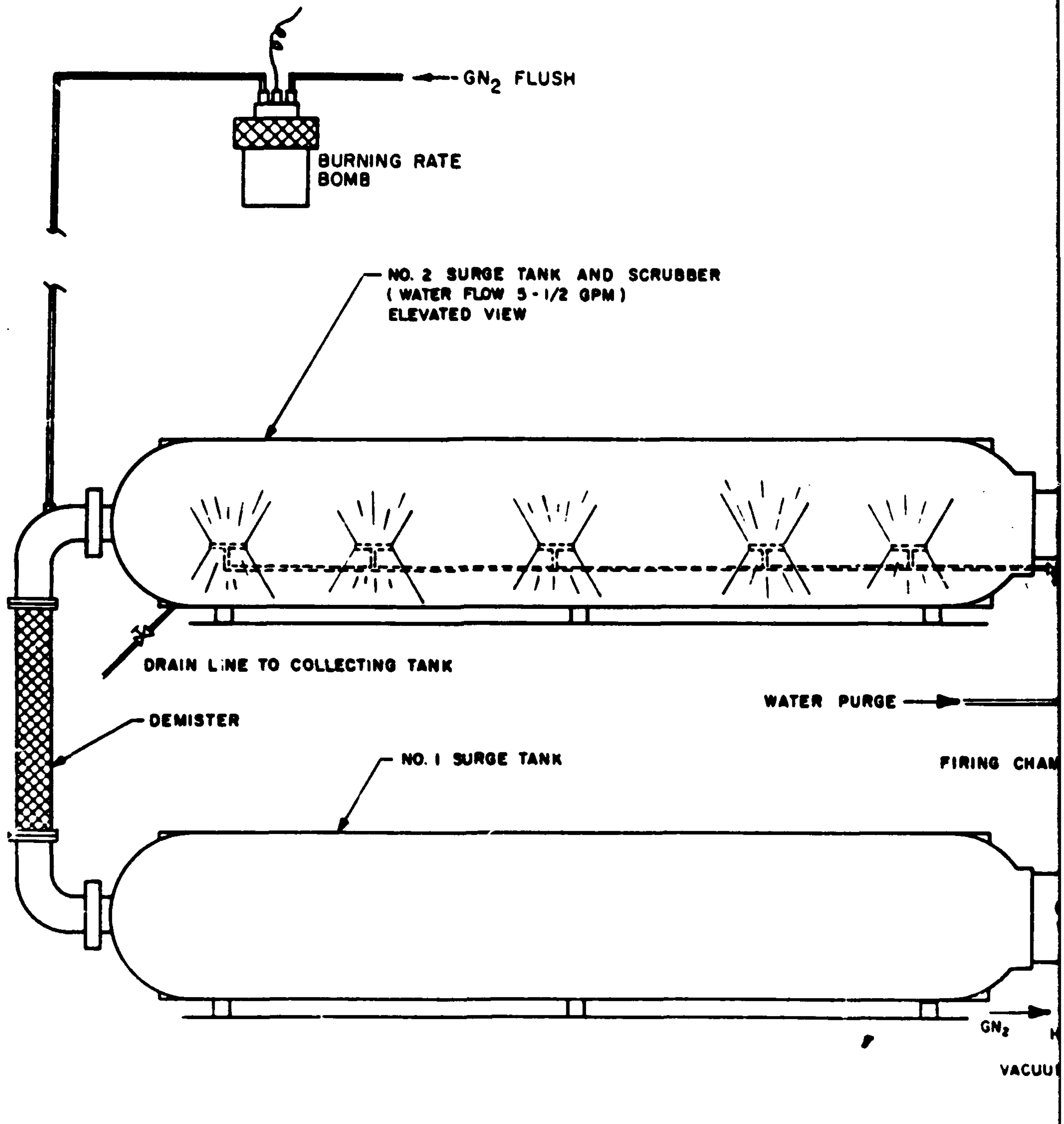
Figure 3. Combined Toxic Propellant Mixing and Firing Equipment


GN2 FLUSH
BURNING RATE BOMB
NO. 2 SURGE TANK AND SCRUBBER
(WATER FLOW 5-1/2 GPM)
ELEVATED VIEW
DRAIN LINE TO COLLECTING TANK
WATER PURGE
DEMISTER
NO. 1 SURGE TANK
FIRING CHAM
GN2
VACUU

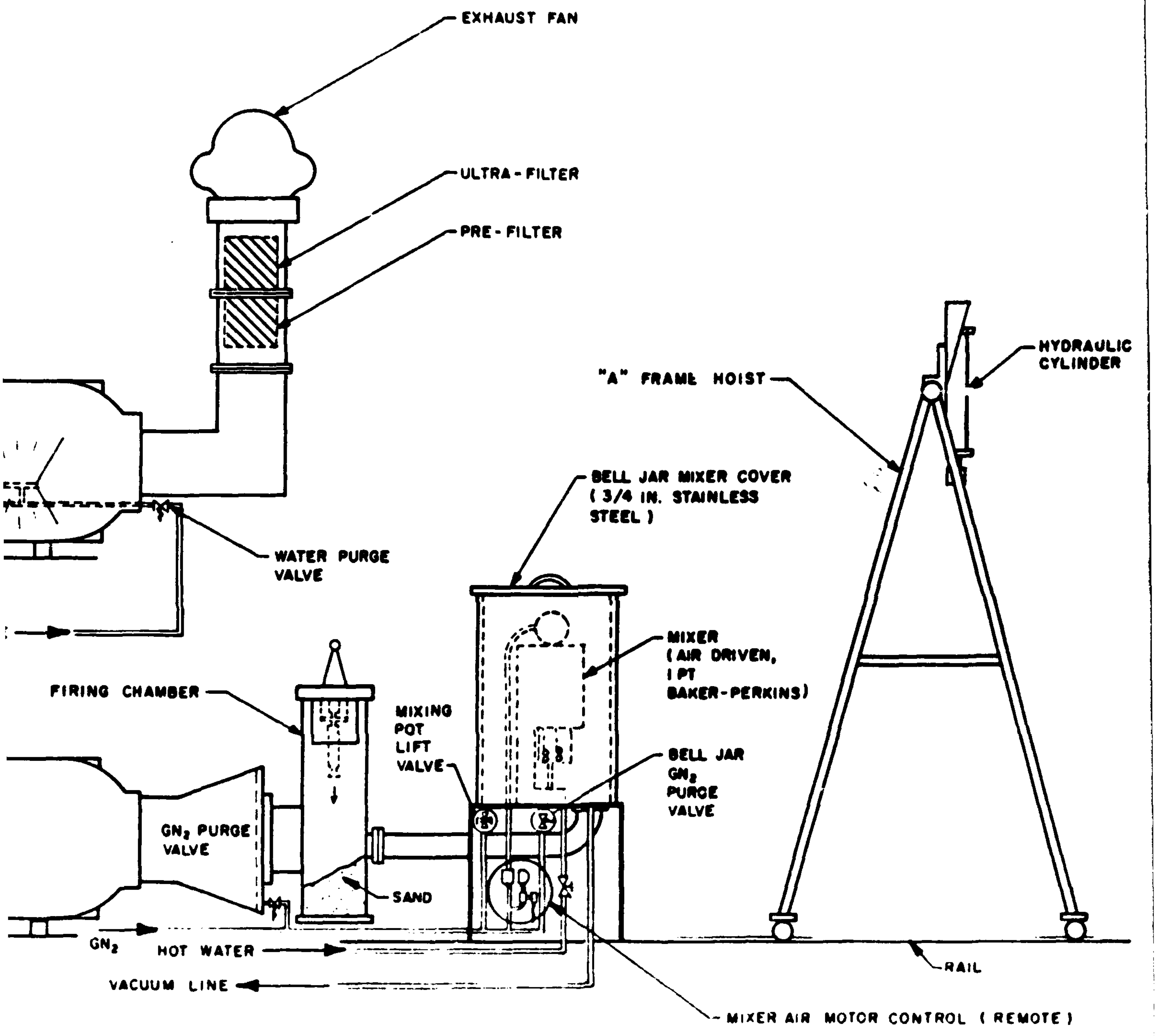


Figure 4. Toxic Propellant Mixing and Motor Firing Facility

2

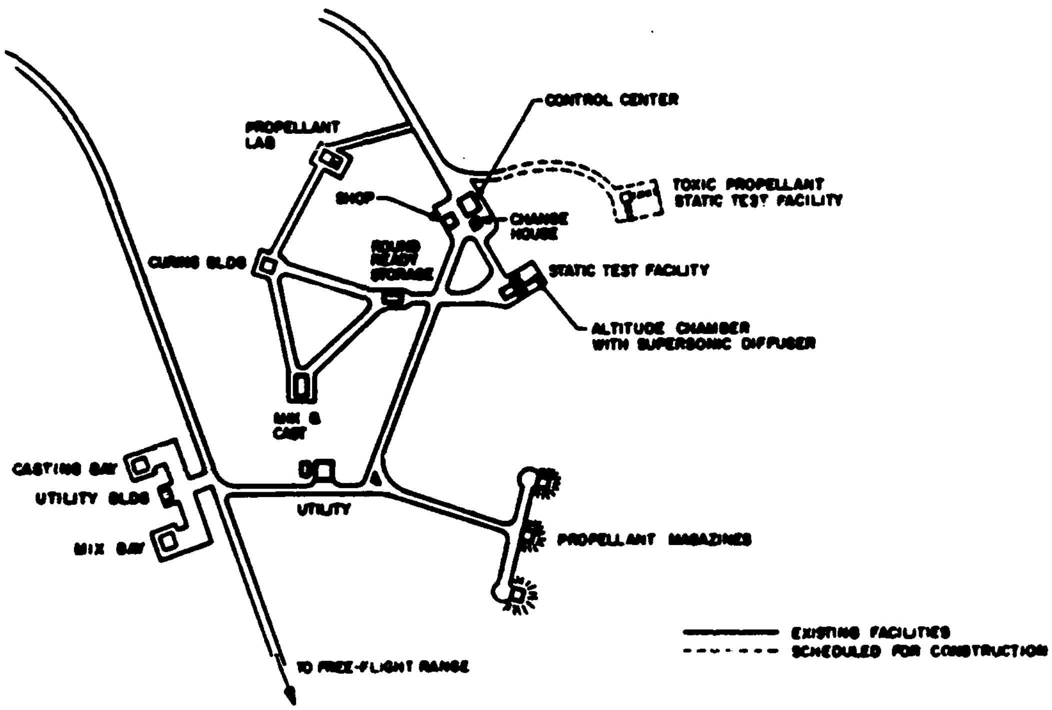


Figure 5. Remote Solid Propellant Facility—Reno, Nevada

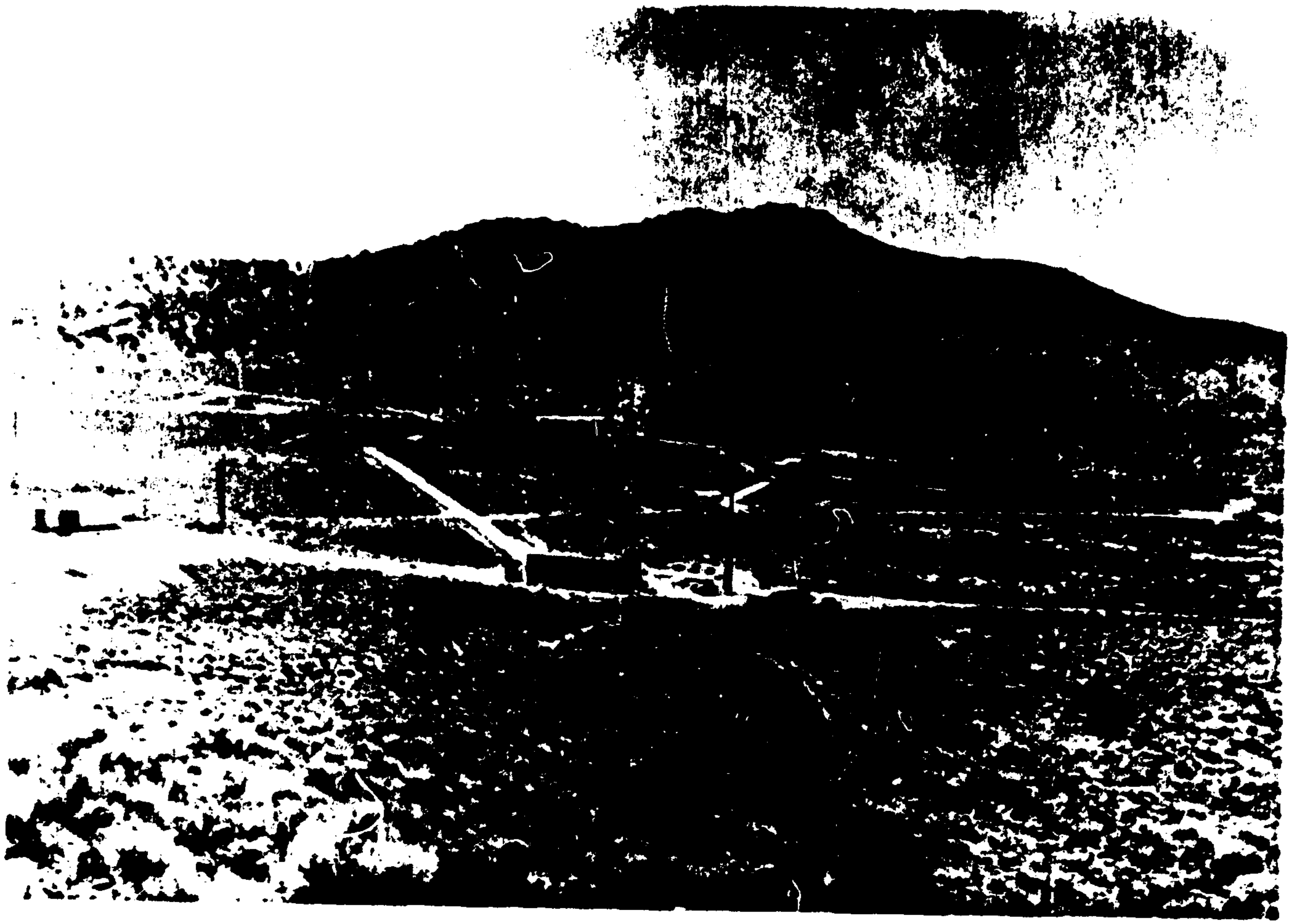


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Figure 6. Reno Solid Propellant Research Facility

1.3.3 The existing facility is designed around a reinforced concrete blockhouse which has been designed to serve as the control center for the static test stands. The building is provided with an oscillograph and strip-chart recorders and television monitors. Control cables connect the control center to the static test cells to facilitate remote test firings.

1.3.4 The interior of the mixing and casting building facility (Fig. 7) can be controlled from within the building behind a concrete barricade. The mixing facility consists of a two-room building separated by an 18-inch reinforced concrete wall. One of the rooms is the mix cell which now contains a 1-gallon vertical Baker-Perkins mixer and a dry box for the transfer and weighing of beryllium powder. The walls of the bay are of light construction designed to come apart in case of an explosion. The other room contains the mixer controls and facilities for preparing and weighing propellant ingredients.

1.3.5 A curing building, three storage magazines, and a storage building complete the existing solid propellant facilities. A utility building contains a well, pumping equipment, and standby electrical generators. The facility has been laid out on a quantity-distance basis of 400 feet between each building. This distance provides for a much greater propellant safety capability than can be achieved in the present buildings at the Propulsion Field Laboratory.

1.3.6 The remote location and design of this facility permits the testing of beryllium propellants without the use of containment tanks and scrubbers. During static testing of beryllium-containing motors, the operating personnel will be in the control center, which can be sealed until the surrounding atmospheric area is clear.

1.3.7 The test building contains two static test cells and a motor preparation area. Tests can be conducted either from behind the concrete wall of the test cell , or for hazardous tests, from the control center. A thrust stand is installed in one test pit for the Rocketdyne 6- and 15-pound ballistic motors

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Figure 7. Casting and Mixing Facility

and was designed to handle motors containing up to 50 pounds of propellant. The thrust stand is shown in Fig. 8. A simulated altitude vacuum chamber and diffuser system has been installed in the other test bay. A series of 15-pound motors containing a beryllium propellant has been fired at this facility under the current contract. These tests are conducted under close supervision of the Air Force and Rocketdyne Industrial Hygiene & Safety personnel, and the spread of beryllium contamination is being studied by means of various sampling techniques. Later sections of this report will cover the results of the sampling program.

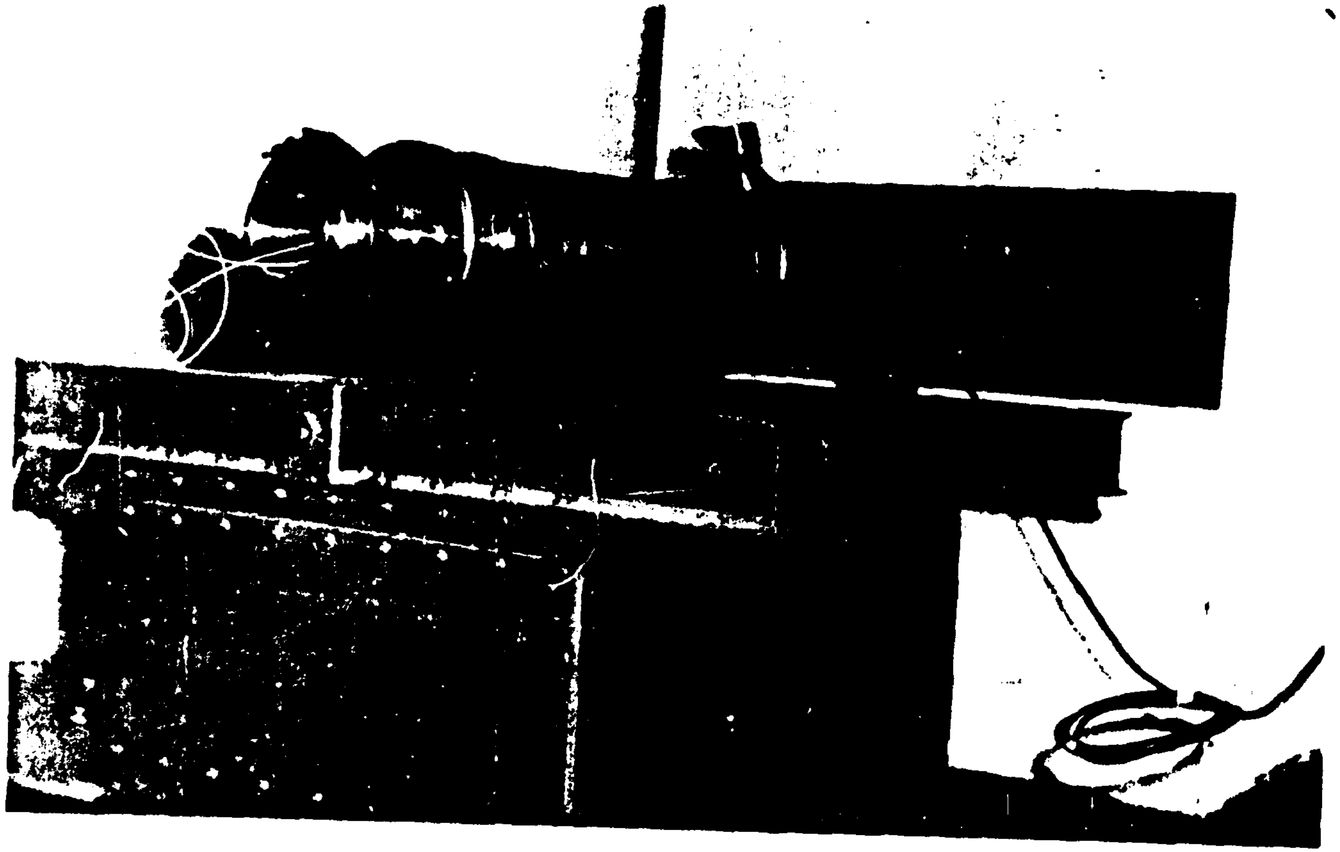

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Figure 8. Thrust Stand in Static Test Facility

2.0 PHYSIOCHEMICAL PROPERTIES

2.1 The Physiochemical properties of beryllium and beryllium oxide are given in Table 1.

TABLE 1

PROPERTIES OF BERYLLIUM AND BERYLLIUM OXIDE

Property	Be	BeO
Molecular Weight	9.013	25.0
Boiling Point, C	2970	3900 (approx)
Melting Point, C	1278	2530 ±30
Density, g/cc	1.85	3.025
Heat of Combustion, kcal/g	17.2	

2.2 Beryllium and beryllium oxide may be considered to be insoluble in water. Deposition of either compound in natural or potable water supplies would lead only to minute quantities of the material remaining in solution, although concentrated suspensions may occur. Other beryllium compounds may be highly soluble in water, resulting in excessive concentrations in the water. However, such soluble compounds are generated by the compositions currently being studied in only minor quantities.

2.3 Finely divided particles of metallic powders may spontaneously ignite and burn if dispersed in air, producing beryllium oxide fumes. However, pyrophoric powders of beryllium are believed to be less than 0.1 micron in size. Current studies at Rocketdyne are being conducted to determine the pyrophoricity of such powders. Ultrafine particles must be handled only in inert atmospheres to prevent dispersal and ignition. Particles dispersed in air tend to settle at a velocity which is a function of the diameter and density of the particle. Thus, heavily contaminated atmospheres of airborne particulates including beryllium contaminants tend to be "self-purifying" after varying periods of time depending upon the environmental conditions.

2.4 Beryllium metal has a higher heat of combustion per unit of weight than any other element except hydrogen. The 17.2 kcal produced per gram of material is considerably greater than the heat of combustion for boron and lithium. The implications of this high heat production per unit of weight in the propulsion industry is self-explanatory.

2.5 Standard grade beryllium powders are commercially available with a composition of 97.4 to 99.0% beryllium. A major portion of the impurities is beryllium oxide although trace amounts of carbon, iron, aluminum, silicon, and magnesium may be present. The raw powder may be purchased in various particle size distributions.

3.0 HAZARDOUS PROPERTIES SUMMARY

3.1 Physiological Effects

3.1.1 Beryllium and certain of its compounds are highly toxic when inhaled into the respiratory system. Continued inhalation of relatively minor quantities of these compounds may result in acute or chronic respiratory damage. The more severe form of the disease (berylliosis) may develop many years after the excessive exposure has taken place. Clinical detection of the disease during the early phases is difficult. The primary method of control depends upon limiting the respiratory intake of the various compounds.

3.1.2 Soluble beryllium compounds may cause dermal effects when in contact with the skin of operational personnel. Impregnation of the material under the skin may result in the formation of skin lesions. The dermal effects of contact with beryllium are readily controlled by high standards of personal hygiene. Also, appropriate medical care must be available for corrective treatment.

3.1.3 Limited evidence exists which indicates that beryllium has low toxicity when taken into the gastrointestinal tract. The effects of ingesting food or water containing beryllium appear to be minimal.

3.1.4 Considerable literature is available regarding the physiological effects of beryllium on the body. More detailed information can be found in the documents listed in Appendix A.

3.2 Control Standards

3.2.1 Similar to many toxic materials, certain minimal quantities of beryllium may be deposited in the respiratory system without producing any adverse physiological effects. In general, the pulmonary tract can tolerate this minimal quantity without producing undesirable effects. Based upon this concept, threshold limit values for many industrial materials including beryllium have been developed.

3.2.2 The minimum medical and industrial hygiene standards for the propellant industry of the Air Force Rocket Propulsion Laboratory (RPFOO), Air Force Systems Command, USAF, Edwards, California, are given below:

HEALTH AND SAFETY APPENDIX

A. <u>In-Plant Recommendations</u>

1. The average in-plant atmospheric beryllium concentration should not exceed 2 micrograms per cubic meter. If the result of the daily weighted average concentration, computed on a quarterly basis, for any occupation exceeds the 2 $\mu g/m^3$, but is less than 5 $\mu g/m^3$, the contractor will submit plans for necessary corrections for Air Force approval and provide all personnel exposed in this area with approved personal respiratory protective equipment. If the daily average concentration exceeds 5 $\mu g/m^3$, the operation in question will be halted until the necessary improvements can be accomplished. A daily average concentration exceeding 2 $\mu g/m^3$ will not be permitted to exist for a period exceeding 60 days, except with the specific approval of the Air Force. This approval will be granted only in the event that satisfactory procedures for reducing the concentrations to below 2 $\mu g/m^3$ have been accepted by the Air Force.

2. In the event that a single air sample shows a concentration in excess of 25 $\mu g/m^3$ within the operating area, but is less than 100 $\mu g/m^3$, all exposed individuals will be provided with personal respiratory protection approved by the Air Force and the Air Force will be notified of steps which are being taken to eliminate the high concentration. If the concentration exceeds 100 $\mu g/m^3$ in a single sample, operations will be halted and the necessary corrections made to reduce airborne concentrations at this single point to below 25 $\mu g/m^3$. In no case will concentrations above 25 $\mu g/m^3$ be permitted to exist for a period exceeding 60 days without

the specific approval of the Air Force. This approval will be granted only if steps have been undertaken which can be expected to provide a satisfactory reduction in air contamination.

B. <u>Out-Plant Recommendations</u>

1. In the neighborhood of the plant handling beryllium compounds, the average concentrations at the breathing zone level should not exceed 0.01 micrograms per cubic meter. In the event that the maximum average neighborhood concentration at the ground during any calendar month, as determined on a monthly basis, exceeds 0.01 $\mu g/m^3$, but does not exceed 0.05 $\mu g/m^3$, the plant will be expected to inform the Air Force of specific procedures which will be undertaken to reduce the airborne concentration. In the event that the concentration exceeds 0.05 $\mu g/m^3$, operations will be immediately halted and the necessary corrections made to reduce the average concentration to below 0.01 $\mu g/m^3$. In any event, concentrations above 0.01 $\mu g/m^3$ will be permitted to exist for not more than a 60-day period unless specifically authorized by the Air Force. Such authorization will be forthcoming only if steps are being taken which are expected to result in a satisfactory reduction in effluent material.

2. A maximal concentration of 25 $\mu g/m^3$ for 30 minutes (i.e., 750 $\mu g\text{-min}/m^3$) may be used as a finite number which can be introduced into diffusion prediction formula to estimate the downwind toxic aerosol exclusion radii from a beryllium propellant combustion cloud when siting facilities.

C. <u>Medical Supervision</u>

There should be a medical program supervised by a physician to cover all workers who may be potentially exposed to beryllium and its compounds. A complete medical examination, with particular attention paid to the pulmonary system will be given to all employees prior to assignment to beryllium projects and periodically (at least annually) thereafter, including a termination of employment physical examination. A 14-inch by 17-inch chest X-ray will be taken at each one of these examinations and retained for future reference. If there is any evidence that an individual has chronic beryllicsis poisoning, such an individual should be excluded from any future exposure to beryllium compounds.

D. Sampling Requirements

1. An environmental sampling program will be submitted for approval by the Air Force Rocket Propulsion Laboratory (RPFOO), AFSC prior to the initiation of any operations involving the use of beryllium/beryllium compounds under this contract. This program must permit the evaluation of peak and long-term exposure conditions both in the plant and in inhabited off-site areas. Provisions for obtaining maximal exposure information in the event of an accident such as a production fire or detonation should be included.

2. Meteorological instrumentation for quantitative establishment of data to minimize downwind toxicity hazards will be provided prior to operation of the site. The "Operating Procedures" must provide for utilization of these data in determining when firings may be conducted.

E. Program plans in the over-all area of industrial hygiene and testing procedures shall be coordinated with the Surgeon, Deputy Commander Aerospace System, AFSC, USAF, Attention: Capt. Owen H. Kittilstad, Air Force Rocket Propulsion Laboratory (RPFOO) (DCD-1), Edwards Air Force Base, California, through the Procuring Contracting Officer prior to initiation of effort.

4.0 PROPELLANT PREPARATION, MIXING, AND CASTING--NEVADA FACILITY

4.1 Facilities and Equipment

4.1.1 The preparation of propellant which involves beryllium powder handling, the mixing of the powder with the binders and oxidizer, and the displacement casting of the completed propellant formulation are conducted in the mix and cast building (Fig. 7). The beryllium powder handling and weighing is accomplished in a specially constructed glove box ventilated to the outside atmosphere. Two Cambridge filter-blower units were utilized to exhaust the completely contained box. An access port on the bottom of the box can be opened to permit transfer of the weighed powder to the mix pot which was placed in contact with the bottom of the glove box. A gasket seal prevents air leakage between mixing pot and glove box. A sketch of the glove box is shown in Fig. 9.

4.1.2 The vertical propellant mixer contains a remote mechanism to lower and raise the mix pot into the desired position. When closed, the mixing area is completely contained from the breathing atmosphere.

4.1.3 Following intimate mixing of the ingredients, the formulation has a dough-like consistency with little opportunity for the contained beryllium to become airborne. The casting is conducted in a closed system in the same room as the weighing and mixing.

4.1.4 One wall of the preparation room is a concrete blast wall between the mixing area and the mixing control room. During many operations, the double doors to the mix cell are opened to provide dilution ventilation to the cell interior.

4.2 Operational Procedures

4.2.1 All personnel entering the mix bay during propellant preparation are required to wear a complete set of protective gear including a filter-type respirator. (See paragraph 11.2.2).

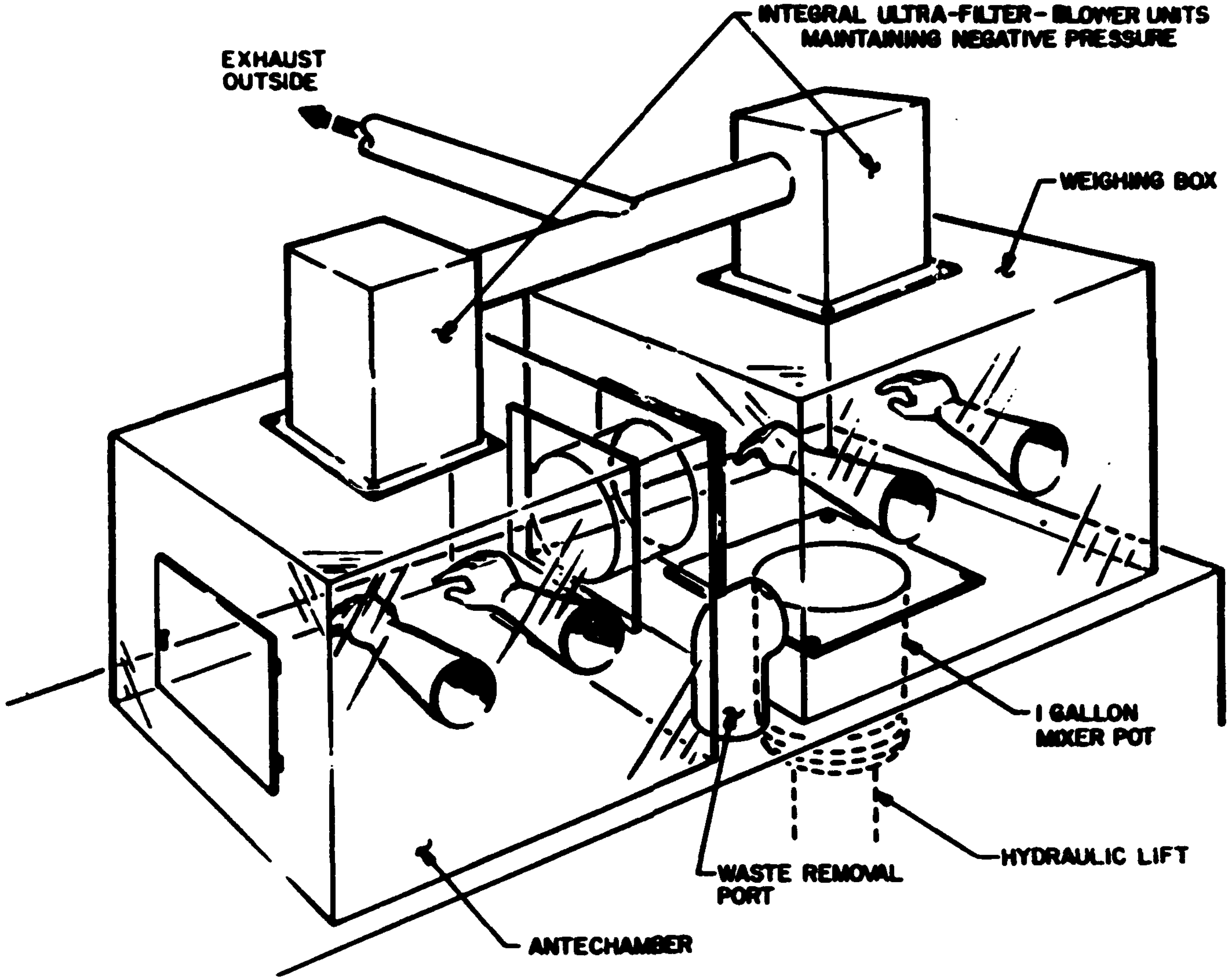


Figure 9. Glove Box Assembly for Weighing Beryllium Into Mixer Pot

4.2.2 Powder-handling techniques involve the weighing and transfer of the powder to the mixing pot. The mix pot is covered with plastic and removed from the glove box after the access port has been closed. The covered pot is transferred to the mixer and placed in a position to be raised. The mix pot is raised in position remotely from the adjacent control room. Some powder dispersal was noted when the blades first contacted the powder as the mix pot was raised into place. When locked in position, the mixer is completely contained.

4.2.3 Following mixing, the propellant is transferred to the casting equipment where it is cast into the desired configuration. The mixing blades and pot are scraped to ensure that all the propellant is in the mold. Displacement casting of the propellant is conducted remotely from the mix bay control room. The completed grain is permitted to cure in the curing building or in the firing bay.

4.2.4 The decontamination of the equipment in the preparation cell is conducted while personnel are wearing a complete set of protective apparatus. All decontamination is done wet to reduce the generation of airborne beryllium dust. (See paragraph 12.0).

4.3 Environmental Data: Preparation Area

4.3.1 Thirty-seven air samples were collected and analyzed in the mixing bay of the mix and cast building during motor fabrication. Nine samples were collected during beryllium handling in a covered plastic container prior to installation of the ventilated glove box. The remaining 28 samples were collected after installation of the ventilated enclosure. Table 2 compares the air sampling results before and after the installation of the ventilated containment.

TABLE 2

MIX BAY AIRBORNE BERYLLIUM CONCENTRATION

Location	Number of Samples	Average Concentration, μg Be/m^3	Maximum Concentration, μg Be/m^3	Minimum Concentration, μg Be/m^3
Mix Bay	9	14.6	59.5	0.97
Mix Bay (with ventilated containment)	28	0.93	10.4	0.003

4.3.2 In addition, 29 samples of the atmosphere were collected in the control room of the mix building. No respiratory protection was required in this area, although the respirator was readily available for use. Table 3 summarizes the results of the airborne contamination found in the mix building control room:

TABLE 3

MIX BAY CONTROL ROOM AIRBORNE BERYLLIUM CONCENTRATION

Location	Number of Samples	Average Concentration, μg Be/m^3	Maximum Contamination, μg Be/m^3	Minimum Contamination, μg Be/m^3
Mix Bay Control Room	29	0.312	5.8	0.003

4.3.3 Smear samples were taken in the mixing building periodically to determine an approximation of the location and quantity of surface contamination that was present. They also served as a means of determining the effectiveness of decontamination procedures. Table 4 summarizes the results of this survey.

TABLE 4

SURFACE CONTAMINATION LEVELS

Location	Number of Samples	Average Contamination, µg Be/100 cm^2	Maximum Contamination, µg Be/100 cm^2	Minimum Contamination, µg Be/100 cm^2
Mix Bay	12	3.62	29.2	0.01
Mix Bay Control Room	4	0.024	0.07	0.008

4.4 Summary and Conclusions

4.4.1 The handling of beryllium powder in the production of propellants can be conducted without excessive exposure to personnel if normal industrial hygiene practices are followed. Ventilated glove boxes or hoods with adequate face velocities of air across the openings readily contain the powders which may be generated. The mixing operation also can be done without generating airborne contamination if the mixing area is adequately closed. Following mixing, the propellant represents only a minor hazard in terms of generating an airborne hazard. Adequate care must be exercised to avoid excessive skin contact with the propellant, since ingredients other than beryllium may have adverse dermal effects.

4.4.2 The initial effort to contain the beryllium powder during weighing and transfer by means of local containment in plastic was not successful, as shown in Table 2. After installation of the glove box, the measured airborne concentrations were greatly reduced. When the mixing bowl is raised remotely in position, visible airborne powder may be generated. Although this operation is conducted remotely, several air samples reflect this excessive dust production in the mix bay. In general, environmental sampling was conducted during periods of time and in locations where excessive contamination was anticipated. The samples showing minimal concentrations normally reflect background conditions or when minimal activity was conducted in the area.

5.0 PROPELLANT CURING AND PREPARATION--NEVADA

5.1 Facilities and Equipment

5.1.1 Propellant curing, trimming, and installation of the grain in the firing hardware were conducted in the motor preparation area of the firing building. The cast grains were transported to the building by hand truck, permitted to cure in the room atmosphere, and trimmed for insertion in the firing hardware.

5.1.2 All personnel manipulating the cured grains during this operation were provided with a complete set of protective clothing and a respirator.

5.2 Operational Procedures

5.2.1 All personnel working on the beryllium propellant were required to wear complete protective gear, including a "high efficiency" filter respirator. Because the beryllium was intimately mixed with the propellant, no excessive airborne contamination was anticipated during these operations. Decontamination was required in areas where the grain was processed to remove bulk trimmings.

5.3 Environmental Data

5.3.1 Air samples taken in the motor preparation room of the firing building revealed concentrations of 0.02 and 2.9 $\mu g/m^3$ during motor firings in the firing bay across the blast wall. No other air samples were taken in the motor preparation area.

5.3.2 Smear surveys for surface contamination in the motor preparation area indicated contamination levels of 0.08, 0.5, and 0.02 $\mu g/100\ cm^2$. These surveys were taken at various dates during the completion of the program.

5.4 Summary and Conclusions

5.4.1 The available air sampling data do not adequately reflect the processing conditions which may be encountered during grain trimming and curing. However, the low surface contamination levels suggest that only very small quantities of beryllium in powder form can be removed from the mixed and formed propellant.

6.0 SMALL MOTOR PREPARATION AND TESTING--PROPULSION FIELD LABORATORY

6.1 Facilities and Equipment

6.1.1 As part of the propellant formulation program, various 2-inch beryllium-containing test motors were produced and test fired at the Propulsion Field Laboratory (PFL) at Santa Susana. The facilities available for beryllium handling at this facility include a laboratory building, an entirely enclosed mixing and firing system, and a change area. These areas are shown in Fig. 2 and 3.

6.2 Operational Procedures

6.2.1 All powder handling was conducted in the ventilated hood or glove box of the beryllium laboratory. Mixing is conducted in an enclosed mixer adjacent to the firing stand. Pressing and curing of the grains was conducted in the beryllium laboratory. All personnel involved in these operations were provided with complete protective gear, including respirators. Personnel were required to decontaminate the area after each day's operation.

6.3 Environmental Data

6.3.1 The air samples collected at the beryllium facilities at PFL are summarized in Table 5.

TABLE 5

AIRBORNE BERYLLIUM CONCENTRATION

Location	Concentration, μg Be/m^3
Office	0.06
Laboratory	0.02
Near Firing Stand During Testing	0.86
Laboratory	0.08
Office	0.005
Laboratory	0.007

6.3.2 Ventilation surveys of the hood were conducted early in the program. The face velocity of air moving into the open hood was 100 fpm. No problems of source control were anticipated based upon this control velocity.

6.4 Summary and Conclusions

The fabrication and testing of the 2-inch beryllium-containing motors was conducted at PFL without the development of excessive airborne beryllium concentrations in the working area. The implementation of normal industrial hygiene practices provides adequate control for the material during the fabrication and test firing of the motors.

7.0 STATIC TEST FIRING--NEVADA

7.1 Facilities and Equipment

7.1.1 The location of the test building at the Solid Research Site, Nevada, is shown in Fig. 10. The cells where the static testing is conducted are open on the east side, and the combustion products are dispersed in this direction. The completed grain and supporting hardware are installed on the mounting supports inside the cell. Instrumentation leads and igniter connections are installed. The test is conducted remotely by the personnel in the control center. Earlier tests were conducted prior to the installation of a concrete pad in front of the firing stand. During March 1963, an extended pad was installed in front of the firing bay to reduce the excessive airborne concentrations of beryllium found in this area during motor hardware cleaning. The concrete pad was installed with curbs which drained the wash water from the pad to a newly installed underground sump.

7.1.2 The location of the control center is also shown in Fig. 10. All site personnel are required to be in the control center during static test firings for blast protection and for protection from excessive airborne contamination. All external openings to the building are closed to restrict inward diffusion of airborne contaminants.

7.2 Operational Procedures

7.2.1 All personnel in the vicinity of the test stand are required to wear complete protective gear during final assembly of the motor hardware, connection of instrument leads, and installation of the firing mechanism. After arming the motor, personnel enter the control room and remain in the closed room for a period of at least 20 minutes after the firing.

7.2.2 After firing, personnel wearing complete protective clothing and respirators re-enter the test stand area for disassembly of the motor hardware and cleaning of the area. The stand area and pad are washed with water prior to working on the assembly.

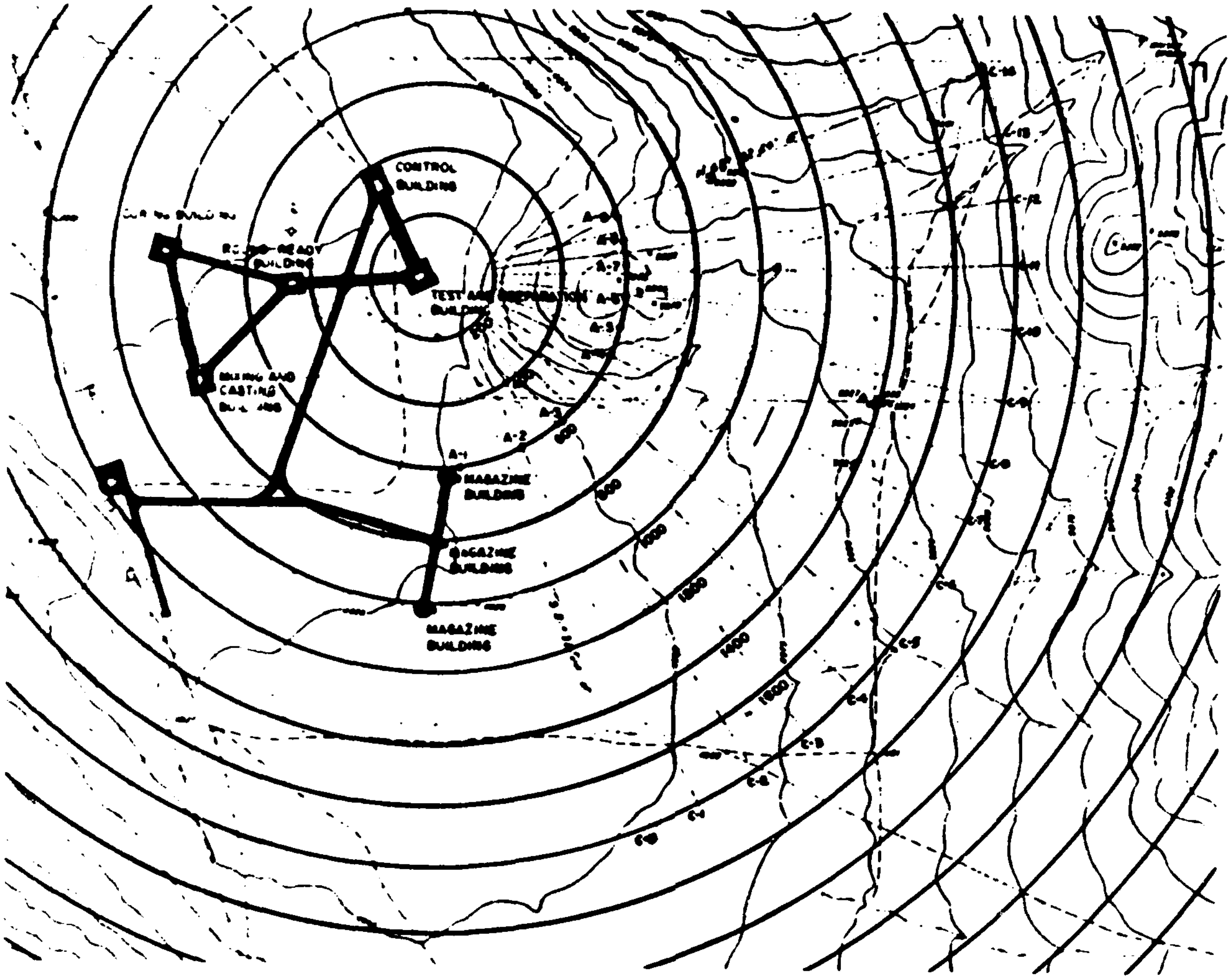


Figure 10. Diffusion Grid Showing Cloud Paths of 15-Pound Be Motor Firings

7.3 Environmental Data

7.3.1 Air sampling was conducted during the various operations associated with the static test firings. Table 6 summarizes the results of the monitoring program conducted in various areas during different operations in the test.

TABLE 6

AIR CONCENTRATION, TEST STAND AREA

Location and Operation	Number of Samples	Average Concentration, $\mu g\ Be/m^3$	Maximum Concentration, $\mu g\ Be/m^3$	Minimum Concentration, $\mu g\ Be/m^3$
Firing Bay During Firing	2	23.8	34.2	13.4
Firing Bay During Cleaning and Motor Removal (before pad installation)	4	26.3	61.5	0.35
Firing Bay During Cleaning and Motor Removal (after pad installation)	4	2.66	5.22	0.03
Control Center Background	1	0.05	....	....
Control Center During Static Testing	10	0.44	2.0	0.0003

7.3.2 Air sampling was conducted at a number of different on-site locations during various phases of the program. Table 7 summarizes the sampling data collected in various locations on the site. These data represent general background concentrations on the site at the time and position designated. Samples No. 4 and 8 indicated somewhat higher concentrations of airborne beryllium than might be anticipated, and are probably the result of local turbulence or sample contamination during handling.

TABLE 7

AIR SAMPLING RESULTS, NEVADA

Date, 1962	Sample No.	Location and Operation	Time On	Time Off	Concentration, μg Be/m^3	Time of Firings
9-18	1	Ten feet north of control center during and after testing	1435	1530	0.04	1445 and 1715
	2	Fifty feet upwind of firing bay	1437	1645	0.01	
	3	Fifty feet upwind of firing bay	1656	1747	6.5	
	4	At grid station A-9 after firing	1745	1800	0.13	
9-19	5	Fifty feet upwind of firing bay during testing	1400	1700	0.28	1515 and 1707
	6	Ten feet north of control center during motor test	1400	1545	0.04	
	7	Ten feet north of control center between firings	1545	1645	10.3	
	8	Fifty feet upwind of firing bay during test	1700	1830	0.26	

7.4 Summary and Conclusions

7.4.1 Monitoring data indicate that excessive airborne beryllium concentrations are present in the firing bay during static test firings and during removal of the motor hardware after completion of a test. The data indicate that a significant reduction in the airborne concentration can be effected by installation of a suitable concrete extension on the firing bay which provides improved decontamination in the area. The significantly higher air concentrations noted prior to installation of the concrete pad suggest that the excessive concentrations were generated by surface contamination of the soil in front of the firing bay.

7.4.2 Control of the atmospheric concentration in the closed control room appears to be satisfactory. No excessive concentrations were noted in this area during the test firings in the firing bay.

7.4.3 The firing bay area was a "restricted area" throughout the completion of the test program. All personnel were required to wear a complete set of protective clothing during entry to this area. No respiratory protection was required in the control center during static testing.

7.4.4 The test firing of beryllium-containing solid propellants was conducted without incident and without excessive personnel exposure, as indicated by the measurements during the program. However, strict adherence to procedures is required by site personnel to minimize the exposure of the test operators during the post-test disassembly work.

8.0 ATMOSPHERIC DIFFUSION STUDIES

8.1 Equipment

8.1.1 An air sampling network was located downwind of the firing bay to determine the concentrations of the beryllium clouds at varying distances from the discharge point. Figure 10 shows the location of the sampling network relative to the Solid Research facilities. The samplers on the 600-foot grid were "high volume" samplers operated from a portable motor-generator unit. The samplers located on the 1800-foot arc were gasoline-driven sampling pumps.

8.1.2 Several techniques were used to determine the cloud's trajectory and the relationship of the cloud's center to the air monitors. Photographic coverage from two fixed movie cameras and one sequence camera was made for each test. By analysis of these films it was possible to approximate the horizontal and vertical travel of the cloud relative to the sampling network. Because the samplers were placed equidistant from each other on the arcs, it is possible to plot a normalized curve of the crosswind distribution of the clouds. Upon comparison with Sutton's point source release equations, the measured concentration was found to be somewhat less than the calculated concentration.

8.2 Sampling Procedure

8.2.1 The sampling network was started about 1 hour prior to the scheduled firing since the gasoline-motor samplers had to be started manually. Also, the monitors operated for about 1 hour after the release of the cloud. The filter papers were changed at the completion of the sampling run for each firing. The papers were immediately submitted to the laboratory for analysis.

8.2.2 All personnel entering the downwind sampling area were required to wear a complete set of personal protective gear, including a respirator.

8.3 Sampling Network Results

8.3.1 Sequential photographs of the cloud diffusion are shown in Fig. 11 and 12. These photographs are fairly typical of the usual cloud dispersion after a static test firing.

8.3.2 Table 8 summarizes the results obtained from the downwind sampling network during various test firings of beryllium-containing motors. The total integrated concentration of beryllium is given at each sampling station on the network in $\mu g\text{-}min/m^3$. The average flow rate of the samplers in m^3/min was divided into the total beryllium in micrograms collected by the sampler to obtain the T.I.D.

8.3.3 Using Sutton's equation for total integrated dosage (T.I.D.) at the ground downwind of an instantaneous source, the Rocketdyne Meteorology Unit calculated the T.I.D. at the 1800-foot sampling.

$$T.I.D. = \frac{2Q}{\pi C^2 \bar{u}(\bar{u}t)^{2-n}} \quad e^{\left[\frac{-h^2}{C^2 (\bar{u}t)^{2-n}}\right]}$$

where

T.I.D.	=	total integrated dosage, $\frac{\mu g\text{-}min}{m^3}$
Q	=	source strength or weight of beryllium released, grams
C^2	=	diffusion coefficient (for isotropic turbulence)
$\bar{u}$	=	mean wind speed, meters/second
$\bar{u}t$	=	sample distance downwind, meters
n	=	stability parameter (range 0 to 1)
h	=	height of smoke plume at sampler, meters

For each diffusion study (Table 9), the values for C^2 were assigned according to the stability parameter n, and the height of the center of the smoke plume, h. The values for n (between 0.22 and 0.27 in this series) were based upon the vertical temperature gradient as indicated by temperatures recorded at different elevations on this site, and the cloud height was estimated from the triangulated motion pictures of each test.

TABLE 8

MEASURED T.I.D. AT VARIOUS SAMPLING STATIONS

Diffusion Study	Date	Source Strength,* grams	Sampling Station	Measured T.I.D., μg Be-min/m^3	Average Flowrate, m^3/min
1	9-18-62	919	A-4	2.9	0.42
			A-5	5.8	0.34
			A-6	0.3	0.45
			A-7	0.3	0.40
			A-8	1.5	0.51
			A-9	1,540.0	0.42
2	9-18-62	920	A-4	0.7	0.51
			A-5	10.7	0.49
			A-6	1.8	0.51
			A-7	1.3	0.42
			A-8	4.5	0.51
			A-9	5,180.0	0.42
			C-10	0.25	0.37
			C-11	0.35	0.37
			C-12	0.26	0.37
			C-13	960.0	0.37
3	9-19-62	920	A-7	1.4	0.40
			A-8	1.6	0.48
			A-9	765.0	0.42
4	9-19-62	920	A-4	44.1	0.48
			A-5	14,500.0	0.42
			A-6		0.45
			A-7	11,600.0	0.34
			A-8	3,700.0	0.40
			A-9	5.3	0.45
			C-4	4.0	0.37
			C-5	1.7	
			C-8	2.1	
			C-10	1,330.0	
			C-11	1,085.0	
			C-12	16.0	
			C-13	4.2	
5	4-11-63	712	C-5	0.41	
			C-6	0.39	
			C-7	0.36	

			C-10	1,330.0		
			C-11	1,085.0		
			C-12	16.0		
			C-13	4.2		
5	4-11-63	712	C-5	0.41		
			C-6	0.39		
			C-7	0.36		
			C-8	0.36		
			C-9	0.56		
			C-10	0.35		
			C-11	0.49		
			C-13	0.30		
			C-14	0.47		
			C-15	0.28		
			C-16	152.0		
			C-17	102.0		
6	4-11-63	715	C-5	0.69		
			C-6	6.5		
			C-7	25.9		
			C-8	151.5		
			C-9	164.2		
			C-10	3.0		
			C-11	0.7		
			C-12	0.41		
			C-13	0.30		
			C-14	0.35		
			C-15	0.35		
			C-16	0.38		
			C-17	0.35		
7	4-13-63	715	C-5	0.30		
			C-6	0.41		
			C-7	0.34		
			C-8	0.52		
			C-9	0.35		
			C-10	0.30		
			C-11	0.31		
			C-12	0.34		
			C-13	0.29		
			C-14	0.32		
			C-15	0.35		
			C-16	0.36		
			C-17	0.84		

*Mass of beryllium collected may be determined by multiplying the T.I.D. times the flow rate. See paragraph 8.3.3 for meteorological considerations during tests.

2

TABLE 9

EXPERIMENTAL VS THEORETICAL DATA
ON CLOUD DIFFUSION

Diffusion Study Number	Date	Calculated T.I.D., μg-min/m^3	Measured T.I.D., μg-min/m^3
1	9-18-62	1720	1540
2	9-18-62	2360	5180
2	9-18-62	2140	960
3	9-18-62	216	765
4	9-19-62	14200	14500
4	9-19-62	4180	1330
5	4-11-63	400	152
6	4-11-63	200	164
7	4-13-63	Cloud did not contact samplers	

The mean wind speed ($\bar{u}$) and wind direction were read from recorded data using Beckman and Whitley instruments located in the test area. The value for C^2 (for n = 0.25, and h varying from 50 to 100 meters) was 0.01, the wind direction was from the west to southwest and the speed averaged 5 meters per second. There was less than 0.5 cloud cover on those days.

8.4 Summary and Conclusions

8.4.1 The sampling network provides a means of measuring the average concentration of airborne beryllium at ground level downwind of the release point. Photographs of the cloud path permit estimations of the time that the cloud was in contact with the network, and may be used to verify the path of the cloud in the downwind area.

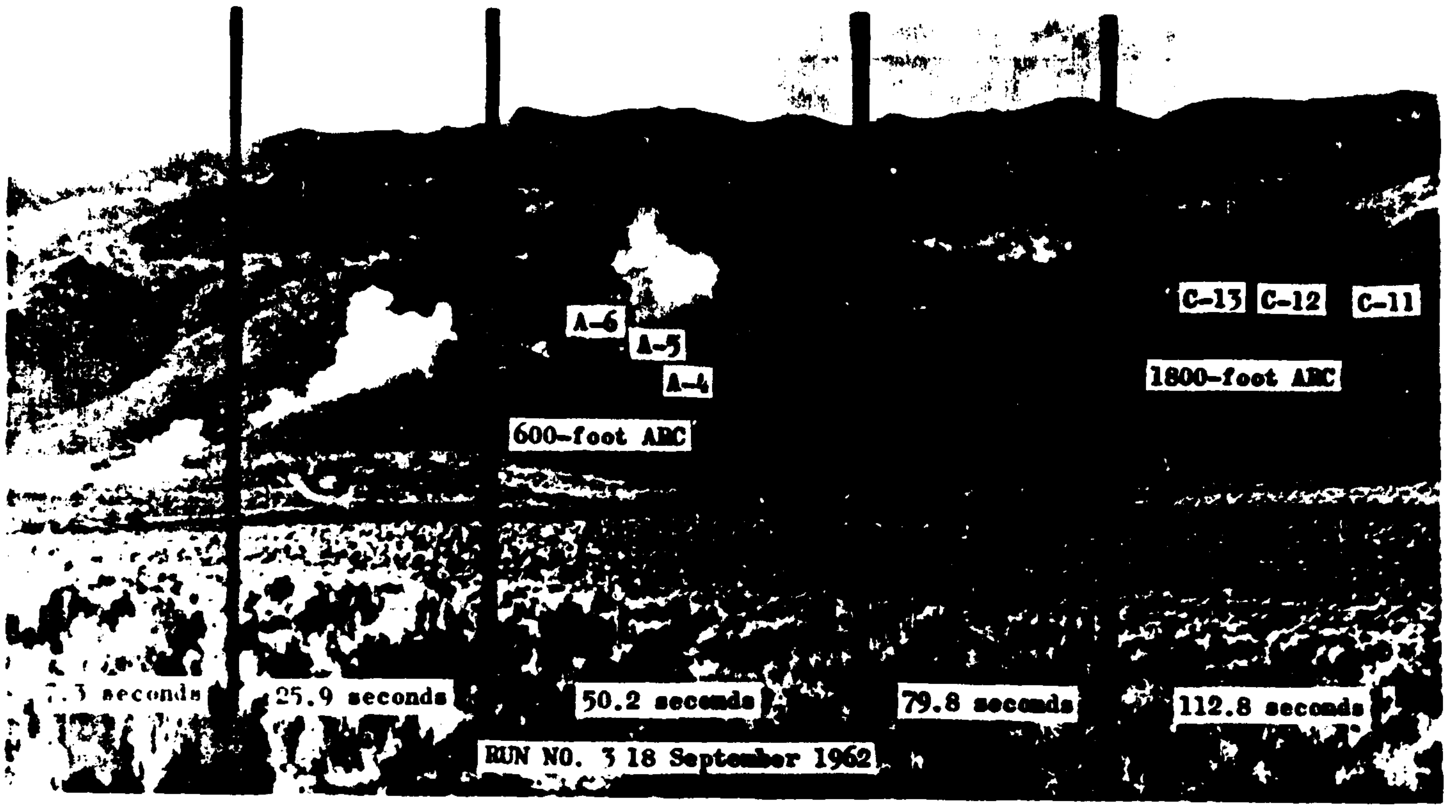
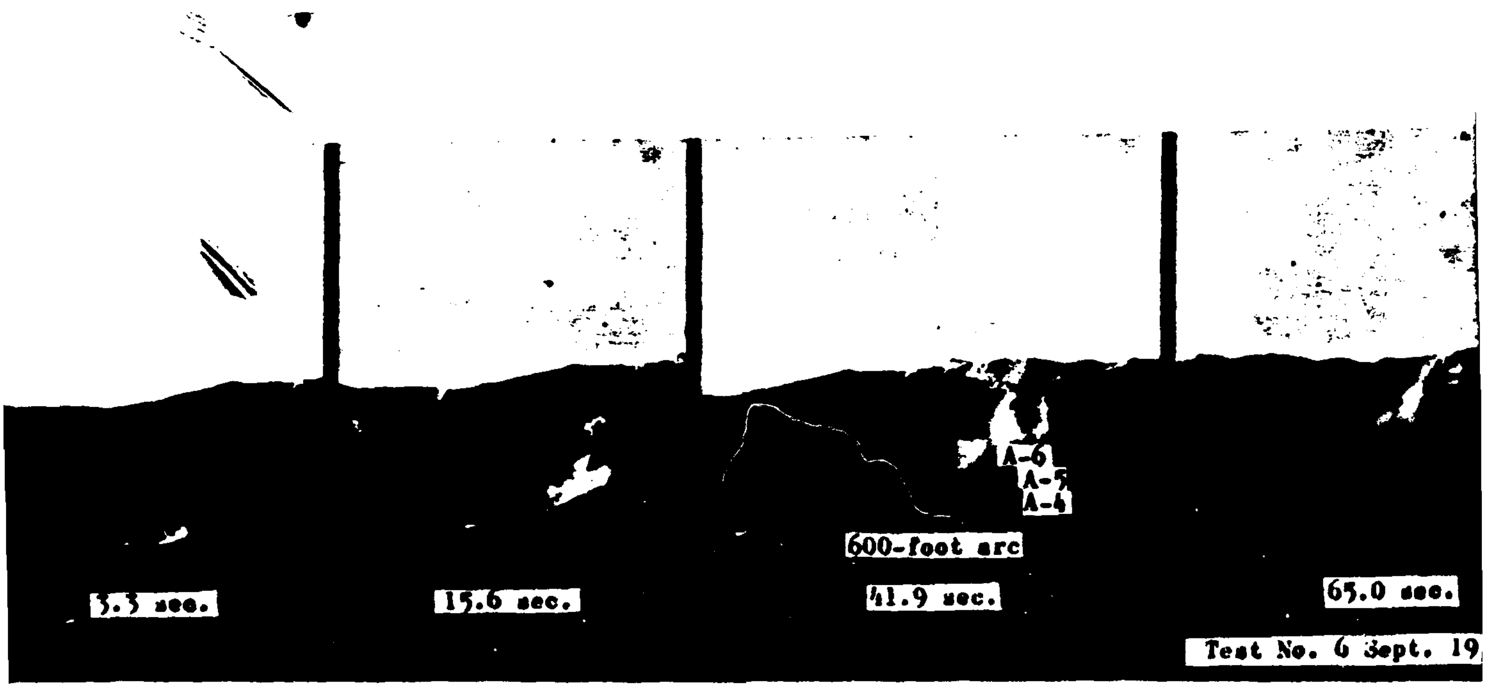
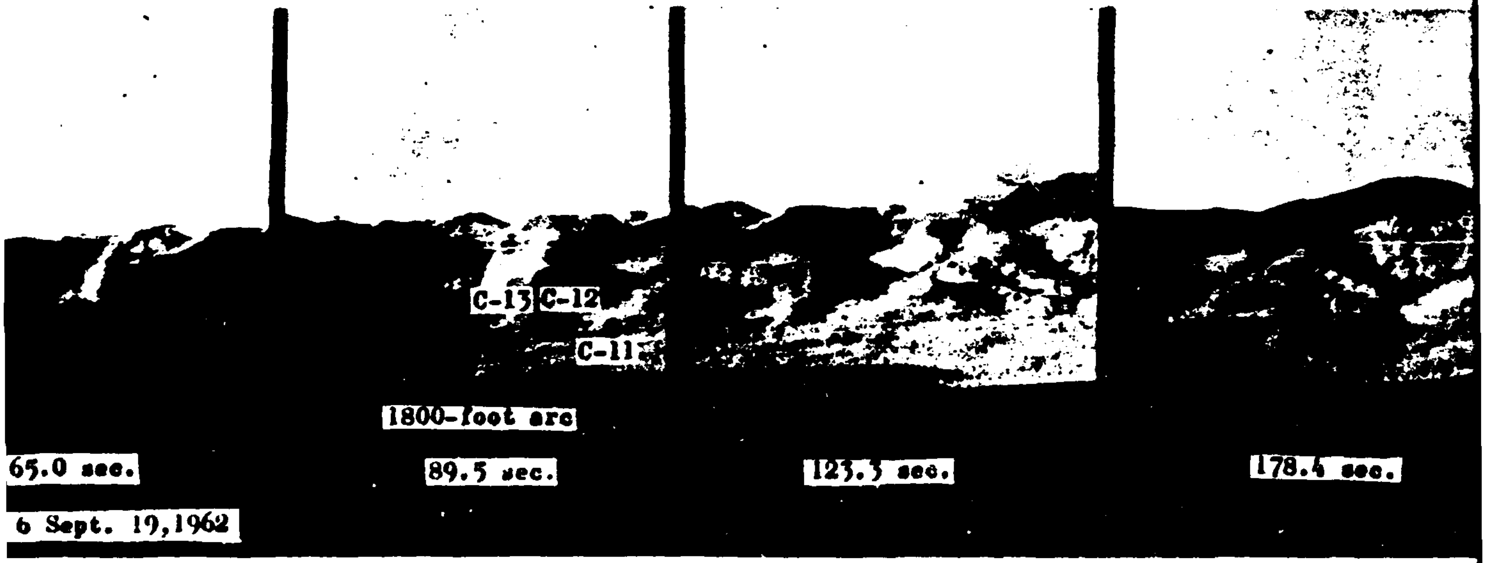


Figure 11. Montage of Cloud Path, Test No. 2



ure 12. Montage of Cloud Path,
Test No. 6


C-13
C-12
C-11
1800-foot arc
65.0 sec.
89.5 sec.
123.3 sec.
178.4 sec.
6 Sept. 19,1962

2

8.4.2 These studies suggest the following conclusions:

1. In most cases, the methods of calculating the downwind concentration of airborne beryllium appear to yield a higher T.I.D. than the measured value. This method of estimating the downwind concentration at the Solid Research Area can be used with reasonable confidence for small motors.

2. Because the samplers on the 1800-foot grid were placed 200 feet apart, the peak concentration probably was not measured. If an infinite number of samplers were used, the measured concentrations would be closer to the calculated values.

3. The average exposure of personnel in the downwind area can be estimated from the calculated and measured downwind concentrations.

8.4.3 More data should be available to substantiate the conclusions reported in paragraph 8.4.2.

9.0 GENERAL ENVIRONMENTAL SAMPLING PROGRAM

9.1 Soil Contamination Surveys

9.1.1 Soil samples consisting of 1 sq ft of soil surface 1 inch deep were collected at the Santa Susana beryllium facility and at the Solid Research Area, Nevada. The samples were sieved to obtain the 325-mesh fraction. This fraction was submitted for analysis. Table 10 summarizes the data obtained from these samples.

TABLE 10

SOIL SAMPLE DATA

Location	Date, 1962	Concentration, µg Be/gm soil
Santa Susana	4-5	1.35
Santa Susana	4-5	0.95
Santa Susana	4-5	0.66
Nevada	7-3	0.19
Nevada	7-3	0.43
Nevada	7-3	None Detected

9.1.2 Additional soil samples were collected during December 1963 following completion of the static test firings at Nevada. The analytical results have not yet been received. A periodic soil sampling program will be continued in the future as a company-sponsored program.

9.2 Off-Site Air Sampling

9.2.1 Background air sampling in the vicinity of the Nevada site was conducted periodically during the completion of the static test firings. Table 11 summarizes the results of this off-site sampling program. Figure 13 shows location of the sampling site.

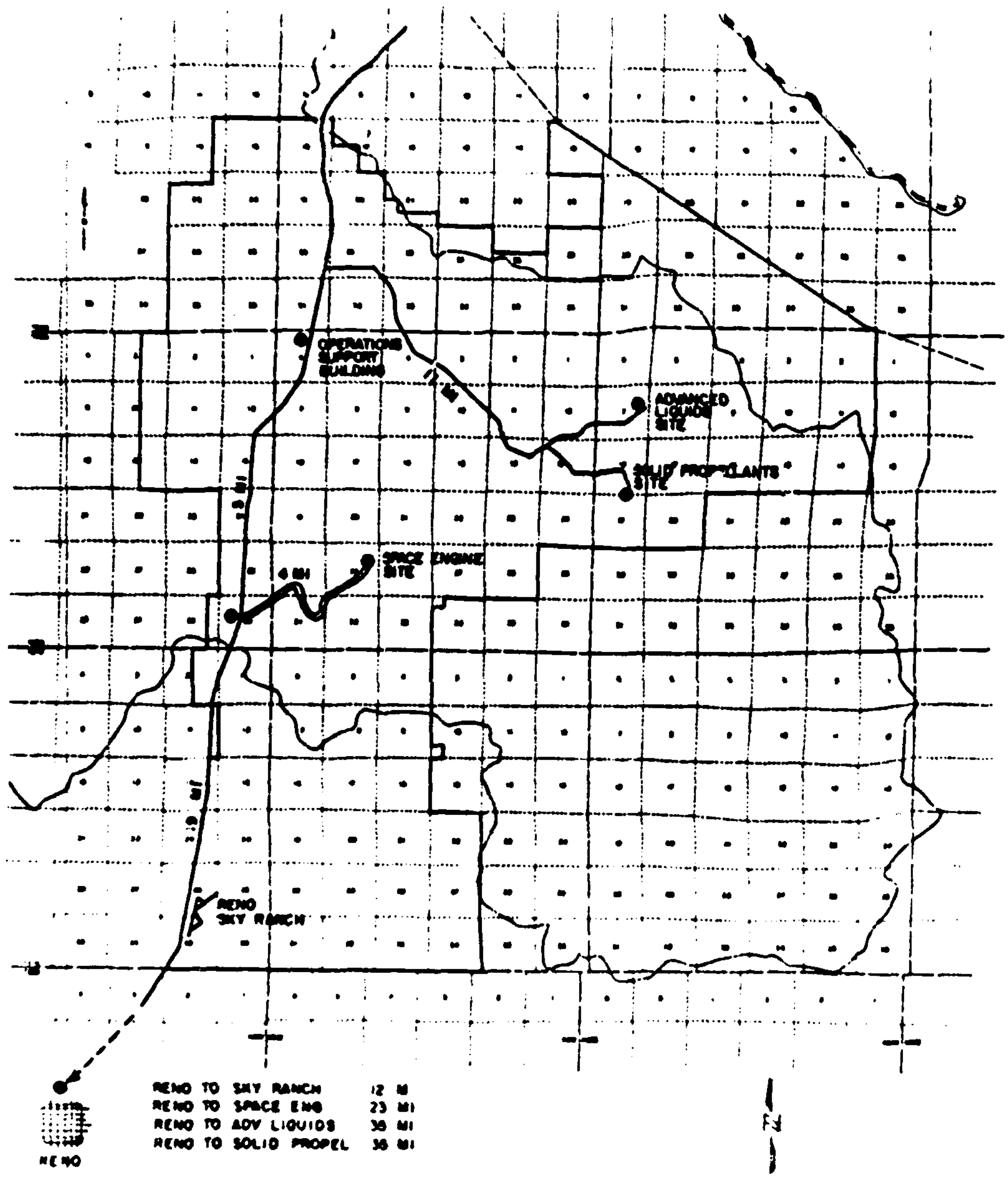


Figure 13. Nevada Facility

TABLE 11

OFF-SITE AIR SAMPLING RESULTS

Location	Start Date	Concentration, $\mu g\ Be/m^3$
Reno, Nevada	7-17-62	2×10^{-4}
Sky Ranch	7-16-62	3.5×10^{-4}
Reno, Nevada	3-22-63	5.9×10^{-4}
Reno, Nevada	3-27-63	2.1×10^{-3}
Reno, Nevada	3-30-63	3.7×10^{-4}
Sky Ranch	3-22-63	3.2×10^{-4}
Sky Ranch	3-26-63	1.5×10^{-4}
Sky Ranch	3-28-63	9.1×10^{-4}
Service Building	12-18-63	4×10^{-4}
Liquids Area	12-17-63	5.2×10^{-3}

9.2.2 Eight additional samples were taken at the above locations during July and August 1962. No beryllium could be detected on the filter papers submitted from these samples.

9.3 Water Sampling and Analysis

9.3.1 Water sampling and analysis were not performed during the course of the program. However, a method of evaporation followed by spectrographic analysis was developed during December 1963. Samples of water from the wells at the Solid Research Area and the Advanced Liquids Area were analyzed during December 1963. Both samples indicated concentrations of less than 0.02 ppm.

9.3.2 Water sampling of surface and underground water in various site locations will be incorporated into future programs at the Nevada site.

9.4 Summary and Conclusions

9.4.1 In general, a more rigorous program for evaluating off-site atmospheric beryllium concentrations should be implemented to adequately evaluate all off-site areas. Off-site sampling should include the populated areas east of the facility. The data presented in Table 11 indicate no excessive atmospheric concentrations of beryllium in the areas sampled. Future program plans specify an expanded environmental sampling program at Nevada.

10.0 SITE CONTROLS, NEVADA

10.1 Visible Warning Systems

10.1.1 All buildings at the Nevada Solid Research Area which are processing beryllium are designated by a flashing red light on the building. A similar warning system is instituted on buildings where formed and pressed grains are stored, processed, or test fired.

10.2 Test Firing Alarm System

10.2.1 Visual and audible alarms are activated at established intervals prior to a static test firing. The visual and audible alarm system provides a warning to all personnel on the site. The procedures for conducting a test are specified in the site operational procedures.

10.3 Physical Restrictions

10.3.1 All access roads to the Solid Research Area are closed during hazardous processing and test operations on the site. Warning signs are posted at the entry to the site. All personnel entering the site must telephone the site control center for permission or instructions prior to entering the area.

10.3.2 Vehicle and personnel barricades are arranged on the site to prevent entry to specified areas because of blast or contamination hazards.

10.3.3 Contaminated areas are designated on the site in the firing bay area and the mix building. These areas have been found to contain excessive surface or airborne contamination at various periods during processing. Complete protective apparatus must be worn by site personnel entering these areas.

10.4 Meteorological Controls

10.4.1 Test firings are only conducted when specified meteorological conditions at the test site have been met. For the Solid Research Facility, static testing may be conducted throughout the day when the wind blows from the south-southwest through north at a speed greater than 4 knots, and with less than 0.6

cloud cover. These parameters were chosen only for safe on-site considerations, since the quantity of material was considered to be too minimal to create an off-site hazard.

11.0 PERSONAL PROTECTIVE EQUIPMENT

11.1 General Site Areas

11.1.2 Personnel employed at the Solid Research Area, Nevada, are not required to wear special protective clothing unless they are required to operate in a specified contamination area or are required to manipulate materials or equipment which may have excessive surface contamination.

11.1.3 Similarly, personnel at the PFL beryllium facilities are not required to wear special protective clothing unless operating in a contaminated area or handling highly contaminated hardware.

11.2 Restricted Areas

11.2.1 The contaminated areas at the various facilities are as follows:

1. Mix Bay, Mixing and Casting Building, Nevada
2. Firing Bay, Firing Building, Nevada
3. Firing Bay Pad and Downwind Diffusion Area, Nevada
4. Beryllium Laboratory, PFL
5. Beryllium Mixing and Firing Area, PFL

11.2.2 The minimum personal protective equipment that must be worn by personnel working in the areas listed in paragraph 11.2.1 is as follows.

1. M.S.A. "Comfoe" respirator equipped with "Ultra Filter" Type H canister or M.S.A. "Dusfoe" respirator with Type H "Ultra Filter" canister. A full-face M.S.A. canister respirator is also available for use at the site.
2. Coveralls which have been treated with flame-retardant materials.
3. Underwear
4. Boots or plastic shoe covers.

5. An air line breathing system is installed in the firing bay. The system utilises bottled breathing air and Scott full-face masks. The masks may be used on the air line or when the air line is disconnected, the mask automatically converts to a filter respirator.

12.0 DECONTAMINATION

12.1 Contaminated Areas, Nevada

12.1.1 The static test area is immediately washed with water following re-entry of personnel after a firing. The exterior of the motor hardware, as well as the test stand and concrete pad, are also washed with water. The hardware removed from the motor is taken to an adjacent area of the pad and washed in water to remove all usable beryllium. Following water wash, the hardware is coated with oil to ensure that the surface will remain "wet."

12.1.2 Similarly, the mix bay is washed with water after each grain preparation. Hardware is decontaminated in water or appropriate solvents to remove beryllium and other residual materials.

12.2 Contaminated Areas, PFL

12.2.1 Decontamination of various areas and equipment is also accomplished with water and a wetting agent. All decontamination operations must be done wet with personnel adequately protected.

12.3 Decontamination of Clothing, Nevada and PFL

12.3.1 All garments worn in contaminated areas of the Nevada site are washed in a machine provided on the site. Clothing from the PFL operations is sent to a laundry specializing in the decontamination of protective clothing. The final rinse water from each batch of laundered garments is analyzed for beryllium by The Smith-Emery Company, Los Angeles, California. Normally, the beryllium content is less than 0.1 μg per liter of water.

12.3.2 Personnel wearing protective clothing are not permitted to wear the garments off the site.

12.4 Personnel Decontamination

12.4.1 Change rooms are available at both facilities to provide an area for the changing of clothing and for bathing. A shower separates the contaminated section from the clean side of the room to facilitate personnel decontamination.

12.4.2 Operational procedures specify that all personnel working in contaminated areas will shower before leaving the site.

13.0 **WASTE DISPOSAL**

13.1 **Liquid Waste, Nevada**

13.1.1 **Wash water from the Nevada test stand is permitted to drain to a seepage pit adjacent to the firing pad. The pit is approximately 15-feet deep and partially filled with rock. The surface is covered with earth over a protective metal cap. Water from the change area is drained to a septic tank system adjacent to the change room.**

13.2 **Waste Disposal, PFL**

13.2.1 **Liquid waste from the scrubber system is filtered prior to release to the local sanitary sewage system. The solid wastes generated in the operation of the laboratory are transported in drums to the Waste Disposal Section, Atomics International, for final disposition with radioactive waste. Since only limited volumes of solid wastes are generated, this method has been selected because of convenience rather than necessity.**

13.3 **Solid Contaminated Waste, Nevada**

13.3.1 **All solid waste is placed in a trench located about 100 feet from the firing bay pad. The trench is about 5-feet deep. The material may either be covered with earth or burned, as in the case of waste beryllium propellant. The burning of waste grains is conducted while utilizing all the precautions normal to a static testing of propellant. Final disposition of the waste includes an earth covering of 4 feet. Efforts will be made to prevent disturbing of the burial site when it is finally closed.**

14.0 ENVIRONMENTAL MONITORING

14.1 Equipment

14.1.1 On-site air monitoring is conducted with high-volume Staplex or Unico air samplers. Whatman's No. 4 filter paper is used as the collecting medium.

14.1.2 Off-site air sampling is done with low-volume samplers using Whatman's No. 41 filter paper as the filter medium. One Gelman Bantam air sampler and one Gelman portable continuous air sampler are used for air sampling in off-site areas.

14.1.3 Fifteen Filtronics custom-designed gasoline-driven air samplers were used on the downwind sampling system. The sampler operates at 13 ±2 cfm using a Whatman's No. 41 filter paper (11 cm) for collection. The downwind air samples collected on the 600-foot arc were taken with 110-volt high-volume samplers powered by motor-generator units installed on the arc.

14.2 Calibration Methods

All high-volume air samplers are periodically calibrated with a venturi flowmeter and water manometer. The primary calibration of the flowmeter has been done by the Rocketdyne Metrology Laboratory. At the time of calibration, the rotometers are set to provide a true air-flow reading at one point. If the rotometer deviates significantly over the total range from the true air flow, the correct flowrate is established by means of a calibration curve.

14.3 Sample Handling

14.3.1 All air sample paper removed from the samplers is folded so that the exposed surface is enclosed and placed in an envelope, the sample data are recorded in a log book, and the sample is submitted to the laboratory for analysis. Periodically, blank sample papers are submitted to determine the extent of cross contamination.

14.3.2 Smear samples of surface contamination are obtained by lightly rubbing a 1-inch-diameter disk of Whatman's 41 filter paper over the suspected surface area. An area of approximately 100 sq cm is wiped by this technique. The sample is folded so that the exposed area is inward, placed in an envelope, and submitted for analysis. Because the technique may vary significantly, the data must be interpreted only as a very rough indication of surface contamination levels.

14.4 Monitoring Techniques

14.4.1 Throughout the course of this program, the primary concern has been to evaluate the beryllium exposure of on-site personnel. Thus, sampler locations have been established in areas where site personnel do not wear respiratory protection; also samples have been taken in those areas where personnel are required to wear respiratory protection. Of secondary concern, locations on site and areas downwind of the static test firings where no personnel are exposed, have been evaluated.

15.0 ANALYTICAL SERVICES

15.1 Sample analysis for beryllium was provided by the following laboratories during the course of this program:

1. Truesdail Laboratories, Los Angeles, California
2. Analyst's Incorporated, Oakland, California
3. The Rocketdyne Research Department, Analytical Chemistry Unit, Canoga Park, California

15.2 The samples were analyzed by the wet method using the Morin technique or by emission spectroscopy.

15.3 To evaluate the capability of the contract laboratory services utilized by Rocketdyne, beryllium standards prepared by Edwards Air Force Base were submitted to both Truesdail Laboratories and Analyst's Incorporated for comparative analysis. Table 12 summarizes the results of these analyses.

TABLE 12

COMPARATIVE BERYLLIUM ANALYSES

Sample Designation	Truesdail Laboratories (μg Be)	Analyst's Incorporated (μg Be)	Edwards Air Force Base (μg Be)
A	0.34	0.24	0.40
B	21.0	20.0	20.3
C	160.0	150.0	151.6
D	2.1	2.4	2.3
E	0.011	0.004	0

16.0 SUMMARY AND CONCLUSIONS

16.1 The Industrial Hygiene and Safety Program (Task I) has demonstrated the feasibility of producing, handling, and test firing beryllium-containing propellants without excessive personnel exposure. To achieve this end result, the task has required action in the following areas of concern:

1. Review all facility installations and modifications of existing facilities and make appropriate recommendations for exposure control.
2. Review installations specifically designed for the control of beryllium and evaluate the effectiveness of the device.
3. Review the development of procedures for various operations conducted on the site to prevent excessive exposure and for other aspects of employee safety.
4. Conduct an environmental sampling program to evaluate the need for controls or to determine where controls are too stringent and may rationally be relaxed.
5. Determine the need for specific personal protective apparatus and make appropriate recommendations regarding the duration and location where such devices are necessary.
6. Train operating personnel in the need for protective devices and apparatus, the hazards associated with beryllium handling and suggest ways to provide control of the process without causing unnecessary work restriction.

16.2 In conclusion, no excessive exposures have been recorded during this program. The handling techniques have been developed to provide adequate control without causing undue restrictions being placed upon operational personnel. The initial attitude of apprehension which was prevalent among operational personnel during early phases of the program has gradually been converted to an attitude of confidence. This confidence is based upon a realistic appreciation of the associated hazard and a knowledge of the means to control the hazard.

APPENDIX A

The following are documents on the toxicity and handling of beryllium and its compounds which may be of interest.

1. Health Hazards From Beryllium. Merrie Eisenluid, Health and Safety Laboratory, U.S. Atomic Energy Commission, New York. (Chapter 12 from the Metal Beryllium, Donald W. White, Jr. and Joseph E. Burke, American Society of Metals, Cleveland, Ohio, 1955, 620-640.
2. Health Protection in Beryllium Facilities. Summary of Ten Years of Experience. A.J. Breslin and W. B. Harris, U.S. Atomic Energy Commission, Health and Safety Laboratory, New York Operations Office, Report No. HASL-36, 1 May 1958, 58; U.S. Office of Technical Services, Washington 25, D.C., $1.75; AMA Archives of Industrial Health, Vol. 19, June 1959, 596-648, Bibliography.
3. Beryllium and Berylliosis. J. Schubert, (Scientific American, Vol. 199, No. 2, August 1958, 27-33).
4. Beryllium Handling—Reducing Health Risks. R.O.R. Brooks, (Nuclear Power, Vol. 3, No. 23, March 1958, 112-114).
5. Beryllium: Hazard Evaluation and Control in Research and Development Operations. E. C. Hyatt, H. F. Schultz, and others (AMA Archives of Industrial Health, Vol. 19, February 1959, 211-220, si references).
6. Beryllium Safe Handling Practices. Webster Hodge, (Defense Metals Information Center, Battelle Memorial Institute. Columbus, Ohio, DMIC Memo 2, 22 September 1958, 13) LD-209 799.
7. Disability Found in Persons Exposed to Certain Beryllium Compounds. H. L. Hardy, (AMA Archives of Industrial Health, Vol. 12, August 1955, 180-181).

8. Pathologic Changes Induced by Beryllium Compounds. L. T. Varwald and A. L. Reeves (AMA Archives of Industrial Health, Vol. 19, February 1959, 190-199, Bibliography).

9. Physico-Chemical Studies of Beryllium Complexes. V. The State of Beryllium in Blood. Isaac Feldman, Jean R. Havill, and W. F. Neuman. (Rochester University, New York, Contract W7401-eng-49, Report No. UR-246, 17 March 1953, 23, 23 references) AD-12 457.

10. Practical Ways to Collect Beryllium Dust. I. A. J. Breslin and W. B. Harris. (Air-Engineering, Vol. 2, No. 7, July 1960, 34).

11. Problems in the Control of Operations in a Beryllium-Processing Plant. Harry M. Donaldson (AMA Archives of Industrial Health, Vol. 19, February 1959, 221-224).

12. Safe Handling Practices for Beryllium. Webster Lodge, Battelle Memorial Institute, Nonferrous Metallurgy Division, Columbus, Ohio. (Metal Progress, Vol. 76, July 1959, 142).

13. Safety Procedure With Beryllium. Henry Allen, (Light Metals, Vol. 21, No. 238, January 1958, 25).

14. Toxicity of Beryllium. J. Cholak, L. H. Miller, and Frank Prince. University of Cincinnati, Kettering Laboratory, Ohio, Contract AF33(600)-37211, Quarterly Progress Report, Technical Report No. AMC-7-665, 1958, 25, 50 references) AD-156-072.

15. Toxicity of Beryllium. C. S. Pomelee. (Sewage and Industrial Wastes, Vol. 25, No. 12, December 1953, 1424-1428).

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2. R-3798-1, Development of High-Energy Solid Propellant Formulations, QPR for Period Ending 30 November 1962, Rocketdyne, a Division of North American Aviation, Inc., Canoga Park, California, CONFIDENTIAL.
3. R-3798-2, Development of High-Energy Solid Propellant Formulations, QPR for Period Ending 28 February 1963, Rocketdyne, a Division of North American Aviation, Inc., Canoga Park, California, CONFIDENTIAL.

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